Hydrogeologic Framework of the Floridan Aquifer System in Florida and in Parts of Georgia, Alabama, and South Carolina

By JAMES A. MILLER

REGIONAL AQUIFER-SYSTEM ANALYSIS

U.S. GEOLOGICAL SURVEY PROFESSIONAL PAPER 1403–B

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON: 1986

ROCKS OF NAVARRO AGE

In outcrop and in the shallow subsurface, Navarroan rocks include the Prairie Bluff Chalk, the Ripley Formation (except for the Cussetta Sand Member), and the upper part of the Demopolis Chalk in Alabama; the Ripley Formation (again, excluding the Cusseta Sand Member) and the Providence Sand in Georgia; and the upper part of the Peedee Formation in South Carolina (Hazel and others, 1977). Downdip, rocks of Navarro age are unnamed except for the Lawson Limestone of northern Florida and southeastern Georgia (Applin and Applin, 1944, 1967). As mentioned previously, beds of Navarro age are thin and discontinuous over much of the area, particularly where these strata are clastic. Navarroan rocks in the study area can be grouped into four general facies: (1) calcareous gray shale interbedded with thin, fine-grained sand in southern Alabama and panhandle Florida; (2) light- to dark-gray, glauconitic, locally shelly and calcareous sand, clayey sand, and clay in northeastern Georgia and South Carolina; (3) dominantly tan to white, pelletal, soft, friable, locally gypsiferous dolomitic limestone (Lawson Limestone) that contains the remains of algae and rudistid pelecypods in north-central Florida and southeastern Georgia (the Lawson is locally very porous owing to a decrease in its micrite matrix, and, where it is porous it is included as part of the Floridan aquifer system); (4) white chalk interbedded with light-gray argillaceous micritic limestone in southern peninsular Florida. The transition from clastic to carbonate rocks is abrupt and takes place along a northeast-trending line in southern Georgia, where both clastic and carbonate materials thin drastically. Navarroan rocks thicken to the northwest and southeast of this line, which is located approximately in the area labeled "Suwannee strait" on figure 3, and along its extension to the southwest. Applin and Applin (1967) thought that this area of thin Navarroan sediments represented a flexure that was positive during much of Late Cretaceous time but subsequently became a negative feature.

Although the Lawson Limestone is quite extensive, it is only in and near the Brunswick, Ga., area that the Lawson is sufficiently permeable to be considered part of the Floridan aquifer system. Elsewhere, rocks of Navarro age are of low permeability. The Lawson can be readily recognized because of its distinctive lithology and the rudistid pelecypod fauna that it commonly contains. Micritic limestone and clayey strata of Navarro age, by contrast, can often be distinguished from older rocks only on the basis of the microfauna that they contain. Rocks of Navarro age reach a maximum thickness of about 600 ft in southern peninsular Florida. For the most part, however, they are less than 200 ft thick.

Fauna characteristic of Navarroan rocks include the rudistid pelecypods mentioned earlier and the foraminifers *Vaughanina cubensis* Palmer, *Lepidorbitoides nortoni* (Vaughan), and *Sulcoperculina cosdeni* Applin and Jordan.

Fine-textured Navarroan strata in the study area were deposited in middle to outer shelf environments. The clastic rocks of Navarro age that lie updip from the chalks and micritic limestones were laid down in inner shelf to shoreline environments.

TERTIARY SYSTEM

PALEOCENE SERIES

GENERAL

Rocks of Paleocene age underlie the entire study area and can be grouped into two general facies categories: (1) a carbonate-evaporite facies that consists mostly of interbedded dolomite and anhydrite and (2) a clastic facies that consists primarily of shallow-marine clay and minor amounts of fine sand and impure limestone. The carbonate-evaporite facies underlies all of peninsular Florida and a small part of southeastern Georgia, and the predominantly clastic facies lies to the north and west of the carbonate platform. The demarcation between these two facies is sharp, and they are assumed to interfinger with each other over a narrow transition zone, although no well drilled to date (1983) has shown such interfingering.

The distribution of the clastic and carbonate facies in rocks of Paleocene age is shown on plate 3, which also shows the configuration of the top of the Paleocene and the area where rocks of Paleocene age crop out. In Alabama and extreme western Georgia, the top of the Paleocene is contoured into the outcrop area. From central Georgia northeastward to South Carolina, the updip extent of the Paleocene is based on well control because Paleocene rocks are mostly overlapped there by younger strata. In South Carolina, the Paleocene is known to extend for a considerable distance to the north of the contours shown on plate 3. Paleocene rocks were contoured only to the limit of the well control used to delineate the Floridan aquifer system.

Plate 3 shows that several large-scale structural features affect the shape of the top of Paleocene rocks. In the western third of the study area, the Paleocene top slopes steadily at a rate of about 30 ft/mi toward the axis of the Gulf Coast geosyncline. Farther eastward, a low area of moderate size extending from Franklin County to Leon County, Fla., represents the

Southwest Georgia embayment. In north-central Florida, a northwest-trending high area is the Peninsular arch. The depression contours to the north of this arch represent the Suwannee strait, which is silled to the east by a slight rise in the Paleocene top. East of this sill, the Paleocene top descends into the Southeast Georgia embayment. The depression contours in southern peninsular Florida represent part of the South Florida basin, which was silled to the west by the Charlotte high (Winston, 1971), a local positive feature. The broad negative area that extends northwestward across east-central Georgia and the southeast-plunging positive feature that parallels it to the northeast are both unnamed. The magnitude of these warps on the Paleocene top shows that they are structural rather than erosional in origin.

The maximum measured depth to the top of the Paleocene Series is 4,680 ft below sea level in well ALA-BAL-30 in Baldwin County, Ala. The maximum contoured depth of the top is below 5,000 ft in the same general area. In southern Florida, the Paleocene top reaches a maximum measured depth of about 3,660 ft in eastern Glades County (well FLA-GL-1).

A primary objective of this hydrogeologic investigation was to delineate and map permeability variations within the Floridan aquifer system. As a later section of this report will discuss, evaporite-bearing rocks of Paleocene age comprise the base of the system over much of the Floridan's area of occurrence. Elsewhere, younger rocks make up the base of the system. Neither permeability nor stratigraphy was mapped below the middle part of the Paleocene (except very locally, in the Brunswick, Ga., area, where all of the Paleocene and part of the Upper Cretaceous are included in the aquifer system). No isopach map of Paleocene rocks was constructed because the base of the Paleocene was not mapped. The thickness of clastic Paleocene rocks, however, is known to exceed 1,400 ft in Mobile County, Ala. (well ALA-MOB-16). The Paleocene carbonate-evaporite sequence is known to be slightly more than 2,200 ft thick in southern Florida (well FLA-LEE-3, Lee County).

Paleocene rocks in the study area can be assigned to several formations (pl. 2). Of these units, only the upper part of the Cedar Keys Formation of Florida and southeastern Georgia is part of the Floridan aquifer system. Anhydrite beds in the Cedar Keys, which are areally extensive and usually occur near the base of the upper third of the unit, form the base of the aquifer system over most of peninsular Florida. Updip from the Cedar Keys, clayey Paleocene strata that are equivalent to part of the Clayton Formation locally comprise the base of the system. In eastern Alabama and western Georgia, ground water is obtained from limestone of the Clayton Formation, but this limestone is nowhere connected to the main body of Tertiary limestone mapped as the Floridan aquifer system.

At the time of this writing (1984), the boundary between Paleocene and Eocene strata in the eastern Gulf Coast is being revised. The work of Berggren (1965), as well as more recent work (Oliver and Mancini, 1980; Gibson, 1980, 1982a), has shown that rocks in Alabama that were long thought to be part of the early Eocene are actually of late Paleocene age. Some formations (such as the Tuscahoma) that contain Paleocene index fossils in their lower parts only are mapped herein as part of the Paleocene. Most of the recent stratigraphic revisions of the Paleocene-Eocene boundary have been in the outcrop area of southern Alabama; most of the mapping done during this study, however, was based on deep subsurface data, and the question of the Paleocene-Eocene boundary therefore becomes a problem only as subsurface correlations are projected toward outcrop. Because the boundary is still in a state of revision, it is important to briefly summarize the history of the problem and set forth the rationale used in this report for assigning a Paleocene age to certain rock units.

Beds in the eastern Gulf Coast that are now known to be of Paleocene age were thought to be part of the Eocene Series before the discovery of a Paleocene fossil mammal in a well in Louisiana (Simpson, 1932). Subsequently, these beds were grouped into the provincial Midwayan Stage, a time-stratigraphic unit comprised of formations that could be dated mostly as Paleocene primarily on the basis of their molluscan fauna. Over the years, the term Midway became synonomous with the term Paleocene. In the eastern Gulf Coastal Plain, the Midwayan Stage included the Clayton, Porters Creek, and Naheola Formations (pl. 2), although the Naheola was recognized to be lithologically similar to beds of the overlying Wilcox Group (Toulmin, 1977). The term "Wilcox Group" itself has been controversial (Murray, 1955, 1961), for "Wilcox" has been used in a time-stratigraphic sense (synonomously with Sabinian Stage to designate early Eocene rocks) as well as in a rock-stratigraphic sense (Wilcox Group). In the eastern Gulf Coast, the Nanafalia, Tuscahoma, and Hatchetigbee Formations (pl. 2) traditionally have been considered to comprise the Wilcox Group and to be of early Eocene age.

More recently, the Paleocene and Eocene section of the Gulf Coast has been correlated with the European section by using planktic microfauna (chiefly Foraminifera and calcareous nannoplankton), which are considered to be worldwide stratigraphic markers (Berggren, 1965, 1971, 1977; Oliver and Mancini, 1980; Bybell, 1980; Gibson and others, 1982). The Nanafalia Formation of Alabama, formerly thought to be of early Eocene age, has been shown to consistently contain the planktic foraminifer *Globorotalia pseudomenardii* Bolli, a worldwide Paleocene form. The generic placement of certain planktic species has recently been revised by some authors. For example, *Globorotalia pseudomenardii* is presently considered to belong to the genus *Planorotalites*; *G. subbotinae* and *G. velascoensis* are thought to belong to the genus *Morozovella*. These revisions, however, are not accepted by all micropaleontologists. The taxonomy used for planktic foraminifers in this report and the range of the different species follow Stainforth and others (1975). *Globorotalia pssudomenardii* has been reported (Oliver and Mancini, 1980) from marl beds in the lower part of the Tuscahoma Formation. Higher up in the Tuscahoma, other marl beds contain *G. velascoensis* (Cushman), a form usually shown on foraminiferal zonation charts as ranging into the latest Paleocene. The base of Eocene strata is considered by some authors to be the first occurrence of *G. subbotinae* Morozova (formerly called *G. rex* Martin). However, Oliver and Mancini (1980) recorded *G. subbotinae*, along with *G. velascoensis*, from the same beds in the upper part of the Tuscahoma. Stainforth and others (1975) showed that the range of *G. velascoensis* overlaps the entire range of *G. pseudomenardii* below, and slightly overlaps the range of *G. subbotinae* above.

In the subsurface strata examined during this study, *G. velascoensis* was found to occur commonly in the same beds with *G. pseudomenardii*; accordingly, beds that contain either of these species are considered to be of definite Paleocene age. Beds in the deep subsurface that contain *G. subbotinae* are herein considered to be of early Eocene age. This zonation becomes a problem only in the outcropping Tuscahoma Formation, which, as an earlier discussion pointed out, contains *G. pseudomenardii* in its lower part and *G. subbotinae* in its upper part. Calcareous nannoplankton from marl beds in the Tuscahoma show that these beds are of Paleocene age (Gibson and others, 1982), and sporomorphs from the uppermost Tuscahoma indicate that the entire formation is probably late Paleocene (Frederiksen and others, 1982).

Downdip, all of the Paleocene and lower Eocene formations that are lithologically different in the outcrop area of Alabama grade by facies change into thick marine clay sequences separated by thin sands. The lithology and electric log patterns of these clays are uniform and the strata can be differentiated only on the basis of the microfauna that they contain. Accordingly, the Paleocene in this study was mapped in southern Alabama and western panhandle Florida on the basis of the highest occurrence of *G. velascoensis*. Rocks containing *G. subbotinae* were mapped as part of the early Eocene. As plate 2 shows, rocks of the Tuscahoma Formation or its equivalents are judged to represent the top of the Paleocene. The Hatchetigbee Formation and its equivalents are considered to represent the base of the early Eocene. Plate 2 also shows that neither the units mapped for this study nor the Paleocene-Eocene boundary as determined by Berggren (1971) and Oliver and Mancini (1980) coincides with the traditional concept of the Midwayan and Sabinian provincial stages.

Cedar Keys Formation

Cole (1944c, p. 28) used the name Cedar Keys Formation for "cream to tan colored, hard limestones which contain *Borelis gunteri* Cole and *Borelis floridanus* Cole in their upper portion." Cole thought that the Cedar Keys was an early Eocene unit and equivalent to the "Midway Formation," which at the time was also considered to be early Eocene. Both the Cedar Keys and the "Midway" are now considered to be Paleocene in age. Cole did not specify a type well section for the Cedar Keys. Applin and Applin (1944) called these rocks the "Cedar Keys Limestone" rather than "Formation," but they, like Cole, neglected to specify a type well. Winston (1976) subsequently designated a well in Levy County, Fla. (Coastal Petroleum Company's #1 Ragland, well FLA-LV-4) as the cotype well for the Cedar Keys and redefined the unit on the basis of lithologic criteria rather than paleontologic criteria. Samples examined by this author confirm the findings of Applin and Applin (1944), Chen (1965), and Winston (1976), all of whom observed that the Cedar Keys is practically everywhere either partially or completely dolomitized and that the unit in most places carries intergranular gypsum that fills much of the pore space in the dolomite. Accordingly, the unit should more properly be designated the "Cedar Keys Formation," the terminology used in this report. The upper part of the Cedar Keys usually consists of gray to cream, coarsely crystalline dolomite that is moderately to highly porous. The species of *Borelis* that characterize much of the Cedar Keys section are not present in this uppermost dolomite, because the dolomitization process obliterated any fauna enclosed in the original limestone.

Approximately the lower two-thirds of the Cedar Keys consists of tan to gray, finely crystalline to microcrystalline dolomite interbedded with white to clear anhydrite that commonly shows an interlithic or "chicken wire" texture—that is, thin, veinlike, contorted partings of dolomite separate large nodular masses of anhydrite. This texture, plus the extensive amounts of anhydrite present in the Cedar Keys, shows that the unit was deposited in a tidal flat type of environment, possibly analagous to but more areally extensive than, a modern sabkha environment. Locally, dolomite strata that are interbedded with the anhydrite contain abundant *Borelis spp.* and the foraminifer *Valvulammina nassauensis* Applin and Jordan, an indication that open marine conditions were reestablished periodically in the tidal flat areas.

The evaporite-dolomite sequence is characteristic of the Cedar Keys of the Florida peninsula (see pl. 3). A sharp demarcation exists between this facies and the clastic Paleocene beds that are part of the Clayton Formation in southern Georgia and its equivalents in panhandle Florida. The Cedar Keys may either interfinger with or grade into these clastic strata. Well data show that the clastic rocks become calcareous near the point where the clastic-carbonate facies change takes place. No well data available to this author show the Cedar Keys in contact with the clastic Paleocene beds, however. The faunal transition between the Cedar Keys and the clastic Paleocene is equally sharp. The *Borelis* fauna characteristic of the Cedar Keys has not been found as of this writing in any well that contains a planktic foraminiferal fauna of definite Paleocene age. Because of this limitation, no definitive age can be assigned to the Cedar Keys, and the unit is placed in the Paleocene in this study solely on the basis of its stratigraphic position. The thin beds of limestone that occur locally at the top of the clastic Paleocene section in the Florida panhandle do not resemble the Cedar Keys in any way.

The thick anhydrite beds of the Cedar Keys, where they are present, form the lower confining unit of the Floridan aquifer system. Locally, in the Brunswick, Ga., area, well data show that the Cedar Keys is permeable throughout (rather than only in the uppermost dolomite beds), and the entire formation is considered to be part of the Floridan aquifer system there.

Clayton Formation and equivalent rocks

The Clayton Formation, at its type area in eastern Alabama, consists mostly of coarse-grained sand and minor amounts of sandy, hard to semi-indurated, mollusk-rich limestone. Downdip for a short distance and eastward into extreme western Georgia, the amount of limestone in the Clayton increases. Still farther downdip, the limestone grades by facies change into a massive calcareous marine clay section that contains a few thin beds of sand. The Clayton thins westward and grades gradually into the sandy, silty Pine Barren Member below and the soft, marly McBryde Limestone Member above (pl. 2). In central and western Alabama, the upper part of the Clayton grades into the massive, dark-colored clay of the Porters Creek Formation (Toulmin, 1977). The Porters Creek is for the most part nonmarine to very shallow marine and is not the same as the marine clay that replaces the Clayton downdip. Scattered well data in central Alabama show that the Porters Creek, like the Clayton, grades laterally downdip into this massive marine clay, but a section of thick-bedded, marine, slightly glauconitic sand and gray to brown subfissile clay intervenes between the two formations. Locally, the uppermost beds of the Porters Creek consist of the thin, abundantly fossiliferous Matthews Landing Marl Member.

Most of the Paleocene strata in Georgia have been placed in the Clayton Formation by Herrick and Vorhis (1963). For the most part, the Clayton in Georgia consists of fine- to medium-grained glauconitic sand and clayey sand and smaller amounts of medium- to dark-gray clay. The top of the Clayton in Georgia is commonly marked by a dark-gray, sandy, glauconitic, hard limestone that usually contains casts and molds of pelecypods and gastropods. This limestone is thickest in western Georgia, where it constitutes an important local source of ground water. In eastern Georgia, near the Savannah River, the amount of dark-colored clay in the Clayton increases and grades laterally into the Black Mingo Formation of South Carolina, which consists mostly of dark-colored, carbonaceous clay and thin beds of fine- to medium-grained sand.

In southeastern Georgia, clastic beds of the Clayton merge along a fairly sharp line (pl. 3) with light-colored dolomite of the Cedar Keys Formation. Locally, in updip areas of the central Georgia Coastal Plain, the Clayton grades into dark-colored clay that has been called the Porters Creek Formation, which in turn grades into sands that may be part of the Huber Formation (Huddlestun, 1981).

Undifferentiated Paleocene rocks

Paleocene rocks in most of panhandle Florida, much of southern Alabama, and a small area in extreme southwestern Georgia consist of massive, gray to greenish-gray, subfissile, calcareous, occasionally sandy and slightly glauconitic marine clay. Eastward, this clay grades into argillaceous limestone, which in turn grades into dolomite and dolomitic limestone of the Cedar Keys Formation. Northward, the clay grades into the sand, clay, and limestone sequence of the Clayton Formation. The massive clay is at present unnamed. Applin and Applin (1944) referred to this unit informally as "the clastic lithofacies of the Paleocene" or as the "Tamesii faunal unit" because these clay beds contain a foraminiferal fauna in their lower part that is similar to the fauna of the lower Paleocene Tamesii (Velasco) Formation of Mexico.

Applin (1964) thought the "Tamesii fauna" represented a span of time roughly equivalent to that during which the Clayton, Porters Creek, and Naheola Formations were deposited. The implication is that the massive clay cannot be differentiated into these three units, as Chen (1965) correctly stated. Chen chose to call the massive clay unit the "Midway Formation." The author prefers the term "undifferentiated Paleocene rocks" because it avoids the implication that the term Midway is synonymous with rocks of Paleocene age.

Microfossils diagnostic of undifferentiated Paleocene strata in the study area include the planktic Foraminifera *Globorotalia pseudomenardii* Bolli, *G. velascoensis* (Cushman), *G. angulata* (White), and *G. pseudobulloides* (Plummer). In shallower water deposits, the Ostracoda *Cythereis reticulodacyi Swain, Krithe perattica* Alexander, and *Trachylebris prestwichiana* (Jones and Sherborn) are characteristic.

Nanafalia Formation

The outcropping Nanafalia Formation in western Alabama can be divided into (1) the lower Gravel Creek Sand Member, a coarse-grained sand, (2) a middle, highly fossiliferous glauconitic sand unit informally called the *"Ostrea thirsae"* beds, and (3) the upper Grampian Hills Member, which consists of dark greenish-gray clay interbedded with minor amounts of glauconitic sand (pl. 2). The Gravel Creek Sand is poorly preserved as local erosional remnants in eastern Alabama. The diagnostic Nanafalia oyster *Odontogryphea thirsae* Gabb, characteristic of the middle part of the Nanafalia, ranges upward into the basal beds of the Grampian Hills Member. The upper and middle parts of the Nanafalia in eastern Alabama and western Georgia grade laterally updip into the Baker Hill Formation (Gibson, 1982a), a sequence of interbedded micaceous sand and kaolinitic, bauxitic, and carbonaceous clay. Nanafalia sediments rapidly become finer grained and more marine in a gulfward direction. In southernmost Alabama and western panhandle Florida, beds that are the equivalent of the Nanafalia are gray to greenish-gray marine clays that are indistinguishable from the underlying clays belonging to undifferentiated Paleocene rocks. The Nanafalia clays can be separated from these older clays only in wells where beds of either limestone or calcareous sand occur between the two thick clay units. The outcropping Nanafalia is known to thin as it loses coarser clastics in a downdip direction (Toulmin, 1977; Reinhardt and Gibson, 1980), and subsurface data still farther downdip show that the Nanafalia (upper) part of the massive marine clay sequence is thin in comparison with the lower part.

Tuscahoma Formation

The Tuscahoma Formation in outcrop and in the shallow subsurface is chiefly silt and silty clay containing some fine-grained sand beds. Locally, sand is the dominant lithology in outcrop areas. Some sand beds are glauconitic and fossiliferous, and two such beds have been named the Greggs Landing and Bells Landing Marl Members. The Tuscahoma grades downdip into soft, brown to gray, calcareous, slightly glauconitic clay that contains much fine-grained organic material and a few beds of fine-grained glauconitic calcareous sand.

Still farther southward, the Tuscahoma grades into gray to greenish-gray marine clays that are included in the undifferentiated Paleocene rocks. *Globorotalia pseudomenardii* Bolli and *G. velascoensis* (Cushman) characterize the Tuscahoma. *G. subbotinae* Morozova, which is found in the outcropping Tuscahoma, is not considered characteristic of the formation in the subsurface.

Local Paleocene units

There are several Paleocene units of local to subregional extent in and contiguous to the study area. One of these is the Ellenton Formation in South Carolina (pl. 2), a thin unit of clay and marl (Siple, 1967) whose extent is poorly known and which is dated in only a few places. Although the Ellenton is possibly equivalent to basal Paleocene deposits in the Charleston, S.C., area (G. S. Gohn, written commun., 1983) that were called Beaufort(?) Formation by Gohn and others (1977), well control is not sufficient to correlate the two units exactly. Faye and Prowell (1982) assigned an early to middle Paleocene age to cored materials in Burke County, Ga., that they thought belonged to the Ellenton Formation. Another such local unit is the Naheola Formation in Alabama, which consists of the lower Oak Hill Member (a laminated dark-colored silt, clay, and sand sequence that is locally fossiliferous) and the upper Coal Bluff Marl Member (a fossiliferous glauconitic sand). The Naheola is not recognized in the subsurface, but its equivalents are possibly part of the massive, unnamed, downdip marine clay of Paleocene age. A third Paleocene unit of minor importance is the Salt Mountain Limestone, a white, massive, dense, microcrystalline to finely crystalline limestone that crops out locally in western Alabama, where it has been upthrown along the Jackson fault zone (Toulmin, 1940; Wind, 1974). The Salt Mountain is thin and discontinuous in the subsurface and occurs as a series of disconnected lenses that typically lie within the upper third of the thick, undifferentiated Paleocene clay sequence.

Depositional environments

Rocks of Paleocene age were for the most part deposited in marine or marginal marine environments. In updip areas, the basal sands of the Clayton Formation represent a transgressive marine sand. Their western equivalents, the laminated, fossiliferous silt and sand of the Pine Barren Member of the Clayton, represent a shallow, restricted marine environment such as a bay or an estuary. Both the Pine Barren and the basal Clayton sands were succeeded by soft, micritic (McBryde Limestone Member) to shelly, sandy limestone that represents a shallow, open marine environment. A minor regression of the sea followed deposition of this limestone, during which a shallow marine sand (part of the Clayton) was laid down in eastern Alabama and the blocky, massive, nonmarine to very shallow marine Porters Creek Formation was deposited in western Alabama. The Matthews Landing Marl Member of the Porters Creek was deposited in a restricted marine environment during a minor transgression near the end of Porters Creek time. In middip areas, the Clayton Formation and its equivalents are entirely shallow marine. The laminated silty sands of the Tuscahoma Formation were deposited in a restricted marine environment, probably a tidal flat. Periodically, local transgressions of the sea covered the tidal flat and allowed deposition of the Greggs Landing and Bells Landing Marl Members. Farther downdip, the massive marine clay that is the deeper water equivalent of the Clayton, the Nanafalia, and the Tuscahoma was deposited in quiet open-marine water in a midshelf area.

To the south and east of the clastic Paleocene rocks, the Cedar Keys Formation was deposited in a shallow, warm-water, carbonate bank environment. The extensive evaporite deposits of the Cedar Keys represent tidal flat or sabkha-type conditions that existed over wide areas and for a long time on this carbonate bank.

The basal part of the Naheola Formation in western Alabama (Oak Hill Member) represents a fluvial to very shallow marine (tidal flat accompanied by occasional oyster banks) environment. The succeeding Coal Bluff Marl Member of the Naheola was deposited in a restricted marine to very shallow open marine environment. Downdip, the Naheola probably passes by facies change into part of the massive, open marine clay that forms most of the downdip Paleocene. Well control is not available to show such a transition, however.

The Salt Mountain Limestone was deposited in an open marine, quiet, shallow-water environment. The Salt Mountain is thin and discontinuous, possibly as the result of postdepositional erosion. In wells where the Salt Mountain is absent and the Paleocene sequence consists entirely of marine clay, however, no disconformity is known to exist within the massive clay sequence.

The Gravel Creek Member of the updip Nanafalia Formation in western Alabama is a fluvial sand. It is overlain by the *"Ostrea thirsae"* beds and the Grampian Hills Member, both of which were deposited in a restricted marine environment. The Baker Hill Formation, which is the equivalent of the upper Nanafalia in eastern Alabama and western Georgia, was deposited in fluvial and estuarine environments. Downdip, the Nanafalia Formation grades into and becomes part of the massive, marine, undifferentiated Paleocene clay.

The Ellenton Formation is thought to represent a basal shallow marine transgressive deposit that consists in large part of reworked sediments from the underlying Cretaceous. The Beaufort(?) Formation of Gohn and others (1977) consists mostly of marginal marine beds. The overlying Black Mingo Formation is shallow marine for the most part and reflects a slight regression followed by a transgression.

EOCENE SERIES

General

The thick sequence of Eocene rocks that is everywhere present in the study area can be readily divided into rocks of early, middle, and late Eocene age. The rocks mapped during this study as middle Eocene and late Eocene correspond to the Claibornian and Jacksonian provincial Gulf Coast stages, respectively. Rocks of early Eocene age as mapped correspond to the upper part of the Sabinian provincial stage. These relationships are shown on the generalized correlation chart (pl. 2). As the section of this report dealing with the Paleocene Series discusses, the traditionally accepted concept that the Sabinian Stage is equivalent to the Wilcox Group and that both terms refer to rocks of early Eocene age is no longer valid. Many of the units formerly assigned to the lower part of the Sabinian Stage are now known to be of Paleocene age, rather than Eocene (Oliver and Mancini, 1980; Gibson, 1980, 1982a). These units are accordingly included in the Paleocene Series as mapped in this report.

Eocene strata in the study area are extensive, thick, and, where they consist of carbonate rocks, generally highly permeable. The major part of the Floridan aquifer system is made up of Eocene rocks, which commonly show highly developed primary (intergranular) and secondary (dissolution) porosity, particularly in their upper parts. Like the Paleocene rocks, carbonate rocks of both early and middle Eocene age